Assessment of Airplane Seat Pitch Design using Saudi anthropometric data

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Abstract

In a tenacious debate of airline profit versus passenger safety due to shrinking seat pitches and adding more rows in airplanes, this research is conducted to find appropriate seat measurements that allow for a brace position in a typical economy seat. In the last 40 years, airlines have been decreasing seat pitches steadily. In the 1970s, the average seat pitch is around 35 inches and currently it is around 28 inches. The distance reduction between rows of seats raises safety concerns as it can be extremely harmful during an emergency landing when passengers need to adopt the brace position but cannot due to cramped space. Bracing during an emergency landing is extremely vital in reducing impact forces on passengers as many studies showed that the brace position is necessary to increase the chances of surviving a plane crash. The purpose of this research is to use anthropometric measurements to provide airplane designers with different body dimensions needed to design appropriate and safe seating that accommodates the majority of passengers. The findings of this research provide the body dimensions at different bracing postures to ensure that the largest percentage of adults are able to perform a safe bracing position. The data was collected for a hundred male and a hundred female Saudis subjects who resides in Riyadh. The output is listed in a standard anthropometric table that can be utilized from different perspectives. It is believed that this research is the first to address the problem from an anthropometric point of view and it can be used as a base to regulate the distance between rows of seats by government agencies.

Keywords
Anthropometric Measurements, Brace for Impact, Seat Pitch

1. Introduction

It is a common belief that all passengers would certainly die if an airplane crashes. Although, in fact, from 1983 to 2000, 96 percent of occupants survived, according to the National Transportation Safety Board (NTSB) (1). The assumption of a suitable "brace for impact" role is one action that occupants should take to contribute to their survival. There have been explanations of this form of a role for decades in passenger briefings. The aim is to reduce the likelihood of secondary impact accidents, with the primary impact being between the airplane and the ground, and the secondary impact between the passengers and the airplane inside. 'Brace for impact' is an activity in which passengers pre-position their body against the impact they are most likely to have, thus minimizing impact forces and the resulting injuries substantially. Although the positive benefits of bracing seem somewhat evident, public interest in the brace position's function and efficacy remains. One of the most commonly asked questions by crash safety researchers has long been the position that would secure the full range of passengers [2]. Using the then-new dynamic impact test methods, brace location
effectiveness was investigated during the 1980s and the guidelines were updated to reflect the results. At the end of
the 80s of the last century, a vast amount of data on the flail reaction of passengers seated in a variety of configurations
culminated in an attempt to improve crashworthy seats. Specific brace guidelines for several potential seating
configurations have been used to establish these data[3].
The brace positions referred to in Advisory Circular (AC) 121-24B were focused on various recommendations [4].
Subsequent inquiries into accidents resulted in new guidelines on brace positions [5]. These new guidelines were used
as the basis of the brace guidelines found in SAE Aerospace Recommended Practice 4771, as well as guidance from
the Federal Aviation Administration (FAA) and previous research findings [6].
US Airways flight 1549, an Airbus A320, landed in the Hudson River about 8.5 miles from LaGuardia Airport on
January 15, 2009. Four passengers suffered severe injuries directly due to the impact; two passengers sustained similar
injuries to the shoulder. Both described holding similar positions of "brace for impact" in which they put their arms
back in front of them on the seat and leaned over their head on the back of their hands. The NTSB provided several
safety recommendations to the FAA as a result of this accident, one of which said, "Conducting research to determine
the most advantageous location of the passenger brace in aircraft with mounted non-break seats." Issue new guidance
material on passenger brace positions if the study finds it necessary [7]. As a result of Injuries suffered by passengers,
the uncertainty of passengers as to the correct brace position, and newer technologies used in seats brought to the
forefront a need to examine the usefulness of the brace position to assess if the recommended positions were still
suitable for the widest range of occupants. where Some recent study data were available for that, but the impact of the
seatback folding over was not explicitly addressed [8].
In addition, the Civil Aerospace Medical Institute (CAMI) completed a more comprehensive project that assessed the
passenger brace position for the three most common forms of seat-hinge mechanisms: energy absorbing break-over,
full break-over locked-out, thus complying with the NTSB call to determine the most advantageous passenger brace
position in airplanes with non-break over seats installed. This assessment included a thorough occupant injury risk
assessment, containing current regulatory criteria and additional criteria that may be informative, and is a component
of a research task of FAA Aviation Safety to study injuries that could obstruct outflow after a crash.
For that every time a person travels by airplane, they are constantly reminded of the proper brace position for each
type of seat. Thus, the importance of the "brace for impact" position is well documented. The brace position is an
action in which occupants pre-position their body against whatever they are most likely to impact, and thereby
significantly reducing impact forces and the resulting injuries. The aim of this research is to make sure that the Saudi
citizens are accounted for regarding the seat pitch of an economy seat. The brace position that recommended by the
Joint Aviation Authorities was “The upper body should be bent forward as far as possible with the chest close to the
thighs and knees, with the head touching the seat in front. The hands should be placed on top of one another and on
top of the head with the forearms tucked in against each side of the face”. Whenever the seat configuration and seat
pitch do not allow the passenger to adopt this position, the passenger should try to brace as close as possible to this
recommended position. The seat pitch is the distance between the seat back and the seat in front of it.

2. Ergonomics guidelines for aircraft seat
Ergonomics or human factor is the scientific discipline concerned with the understanding of interactions among
humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design
in order to optimize human well-being and overall system performance. In other words, fit between people and
products, tools/technologies, equipment, facilities, procedures, management, environment, etc.
Actually, all of these things interact, and they must all fit one another. Overall, ergonomics should be taken into
account how the product and its design process are tailored to the human body and the environment. In the design
process, the experience of the end-users and their level of satisfaction should be taken into account, especially with
regard to parameters such as dimensions, materials, shapes, etc. that contribute to design comfort. If the consumer is
unsatisfied with the product, their comfort may be negatively affected [9].
From literature, Aminian and Romli [10] summarized the essential design parameters for the aircraft seat as shown in
Table 1 and the range of values for seat design parameters as shown in Table 2.
Table 1 Essential design parameters of aircraft seat

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description and Corresponding Anthropometric Parameter</th>
</tr>
</thead>
</table>
| Seat Height             | • Vertical distance measured from the footrest surface to the back of the right knee [9]  
                          | • Anthropometric measurement - popliteal height [11, 12, 13] |
| Seat Width              | • Measurement from the popliteal to the posterior edge of the buttocks while the subject is in sitting position [12]  
                          | • Anthropometric measurement - Hip breadth [14] + clothing allowance |
| Seat Depth / Length     | • Measurement from the horizontal distance between the behind point of the buttock plate and the back of the right knee (the front edge of the seat to the lumbar support region of the backrest). The knees position should be parallel and 90 degrees [9, 12]  
                          | • Anthropometric measurement - buttock-popliteal length [14] |
| Armrest Height          | • Measurement of the vertical distance between the sitting surface and the underside of the elbow [11, 13, 15]. The subject should sit erect and looking straight ahead with relaxed shoulder and upper arms [9]  
                          | • Anthropometric measurement - elbow rest height [12, 14, 16] |
| Armrest Width           | • The measurement of the width of the armrest  
                          | • Anthropometric measurement - forearm width [17] |
| Armrest Depth / Length  | • Measurement at the horizontal distance from the back of the elbow to the tip of the middle finger, with the hand, extended and right elbow located in 90 degrees position [11, 18]. This distance can also be calculated as forearm-hand length minus hand length [9]  
                          | • Anthropometric measurement - elbow-wrist length height [12, 14] |
| Distance Between Armrests | • Measurement of the maximum horizontal distance across the lateral surfaces of the elbow with the elbow in fixed and resting position against the body [16]  
                           | • Anthropometric measurement - elbow-to-elbow breadth [14] |
| Seat Pitch              | • Measurement of distance from a point on the seat in one row to the same point on a seat in the front or behind row [19] |
| Backrest Height         | • Measurement of vertical distance from the sitting surface to the top of the shoulder (acromion) with the subject seated [11, 18]  
                          | • Anthropometric measurement - shoulder height and acromial (shoulder) height [14, 20] |
| Backrest Width          | • Measurement of the horizontal distance across the upper arms between the maximum bulges of the deltoid muscles [11]  
                          | • Anthropometric measurement - shoulder breadth [14] |
| BackrestLumbar Height   | • Measurement of vertical distance from the sitting surface to the level of the waist, the subject should be in the sitting position [11]  
                          | • Anthropometric measurement - waist height [11] |
| Headrest Height         | • Measurement of vertical distance from the chin to the top of the head [11]  
                          | • Anthropometric measurement - head height [21] |
| Headrest Width          | • The measurement of the maximum breadth of the head above the ears [11, 21]  
                          | • Anthropometric measurement - head breadth [14] |

Table 2. Range of values for seat design parameters

<table>
<thead>
<tr>
<th>Seat Design Parameter</th>
<th>Minimum Proposed Value</th>
<th>Maximum Proposed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Height</td>
<td>30.48 cm to 35.56 cm</td>
<td>31.2 cm to 48.8 cm</td>
</tr>
<tr>
<td>Seat Width</td>
<td>43 cm</td>
<td>First, business and economy class seats are suggested around 59.5 cm, 50.5 cm and 49.5 cm, respectively</td>
</tr>
<tr>
<td>Seat Depth</td>
<td>38 cm to 40 cm</td>
<td>39 cm to 55 cm</td>
</tr>
<tr>
<td>Armrest Height</td>
<td>16 cm to 23 cm</td>
<td>20 cm to 25 cm</td>
</tr>
<tr>
<td>Armrest Width</td>
<td>4 cm</td>
<td>7.62 cm</td>
</tr>
<tr>
<td>Armrest Depth / Length</td>
<td>16 cm to 23 cm</td>
<td>27 cm to 39 cm</td>
</tr>
</tbody>
</table>
Distance Between Armrests
- 54 cm for the nonadjustable seat and between 39 cm to 54 cm for an adjustable seat [17]

Backrest Height
- 18.5 cm to 21.5 cm [28]  
- 64.26 cm up to shoulder and 75.44 cm with headrest [22]

Backrest Width
- 33 cm [24, 27]  
- 52 cm [29]

Seat Inclination
- 0° to 5° [28]  
- 5° to 15° [30]

Backrest Inclination
- 90° to 115° for the short backrest and 120° for high backrest [27]  
- 105° to 135° for first-class and 105° to 128° for business and economy class [23]

Backrest Lumbar / Lumbar Support Height
- 10 cm to 20 cm [28]  
- 17 cm to 28 cm for adjustable height and 20 cm to 24 cm for non-adjustable backrest [27]

3. Methods
3.1. Study Design
A real measurement was used for estimating the Saudi Arabian citizen’s anthropometric data to consider it when designing seat pitches. The rationale for the use of this research design is based on its efficacy for computing quantifiable results in an explicit manner. Moreover, a similar design has been used in other studies conducted in the same discipline.

3.2. Study participants
The study participants were 200 male and female Saudi Arabian citizens (mean age, 22 [4.53] years). Mean weight, and height, were 70.63 (8.04) kg, 165.1 (3.01) cm, respectively. Mean hip height, knee height, buttock-knee length, and sitting height were 95.4 (3.29) cm, 56(2.9) cm, 60 (2.1) cm. Written consent was also acquired to ensure the citizens’ volunteer participation.

3.3. Data collection
The anthropometric data gathered was collected from 200-participant aged 22 on average. (100 females and 100 males).

The minimum space we need is the maximum of males in order to compensate for females who are more likely to be shorter. The seat pitch should account for at least the upper body measurements for males. The ability to bend and the brace is measured through upper body height, thus sitting height is taken as shown in figure 1.

Figure 1. sitting height
4. Results

4.1. Sitting height

Table 3 and figure 2 show the sitting height for male and female, the results show that the mean sitting height for male and female are 83.23 cm and 79.35 cm respectively. As well as the 95th percentile for the male is 90 cm. As we can take this height on the basis that, it is the highest height because the rest are considered shorter.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean (cm)</th>
<th>SD (cm)</th>
<th>90th Percentile</th>
<th>95th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>79.35</td>
<td>4.53</td>
<td>85.05</td>
<td>86.53</td>
</tr>
<tr>
<td>Male</td>
<td>83.23</td>
<td>4.01</td>
<td>89</td>
<td>90</td>
</tr>
</tbody>
</table>

Figure 2. Sitting height data

4.2. Effect of brace for impact angle on the Seat Pitch

The results show that the seat pitch increased as the brace for impact angle increased for males and females as shown in table 4 and table 5. As well as the seat pitch for males, more than seat pitch for females see figure 4 and figure 5.

<table>
<thead>
<tr>
<th>Angle</th>
<th>30°</th>
<th>45°</th>
<th>90°</th>
<th>95°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentile</td>
<td>90th</td>
<td>95th</td>
<td>90th</td>
<td>95th</td>
<td>90th</td>
</tr>
<tr>
<td>Seat Pitch (in)</td>
<td>18.53</td>
<td>18.83</td>
<td>25.8</td>
<td>26.07</td>
<td>36.07</td>
</tr>
</tbody>
</table>

Table 4. Effect of brace for impact angle on the Seat Pitch for males

<table>
<thead>
<tr>
<th>Angle</th>
<th>30°</th>
<th>45°</th>
<th>90°</th>
<th>95°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentile</td>
<td>90th</td>
<td>95th</td>
<td>90th</td>
<td>95th</td>
</tr>
<tr>
<td>Seat Pitch (in)</td>
<td>11.79</td>
<td>11.99</td>
<td>24.70</td>
<td>25.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>90th</td>
<td>95th</td>
<td>90th</td>
<td>95th</td>
</tr>
<tr>
<td></td>
<td>11.79</td>
<td>11.99</td>
<td>24.70</td>
<td>25.66</td>
</tr>
</tbody>
</table>

Table 5. Effect of brace for impact angle on the Seat Pitch for females

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5. Discussion

Safety is the primary factor that affects how people decide what seat pitches to apply. Each country has different anthropometric data and secular trends. When deciding seat pitches, people should consider the 95th percentile of the world such that they do not exclude other people. When we began looking into the topic of this project, we noticed that Saudi Arabian citizens have not been taken into account when designing seat pitches due to the lack of Saudi anthropometric data. The research should account for a wide range of people sizes, taking into consideration two important aspects; safety factor and variation of size over time. It is only virtuous to ensure that seat pitches accommodate the 95th percentile of people since it is a safety issue and we need to make sure that all passengers can brace easily. Also, seat dimensions should include an allowance for older users as the proportion of older people in the population is growing significantly. Today there are almost a third fewer older people than there are younger adults. By 2020 their numbers will be equal, and by 2030 older people will outnumber younger adults by a fifth and this is likely to be represented within the flying
population. While conducting this research, we have deduced that an allowance of 1 inch should be added to the seat pitch as an added precaution since this is a life or death issue. First, we included the allowance, to help ensure that passengers can quickly and easily adopt the brace position in the case of a sudden emergency landing. Secondly, we wanted to make certain that passengers can brace even if the seatback in front of them was reclined. In tables 1, we found the seat pitch needed to adopt the brace position at different angles when we added one inch of allowance to the seat pitches. From our research of different airplane models and their economy seat pitches, we found that the most prevalent seat pitch is 28.8 inches. After calculating the seat pitch that accommodates the 90th and 95th of Saudi citizens at different angles with the back of their seats (Table [4]), the results show that for males at 30 and 45 degrees all subjects can perform the brace position. but at 90 degrees people need more space to brace at that angle. No one can perform it. We should focus on the males calculation since they have larger dimensions than females and this way we can include a bigger part of the population. From this data, we conclude that if the safest angle is 30 or 45 degrees, we do not need to increase seat pitch as all passengers will be able to brace. However, if it is found through more research that a bigger angle is needed to minimize impact testing we need to increase the seat pitch as passengers cannot adopt the brace position this way without bending their backs or twisting in an uncomfortable position.

6. Conclusion
The results of the analysis revealed that the most prevalent seat pitch fits more than 95th%ile of Saudi males at an angle of 45 with the back of the seat. Also, during our research, we noticed that two vital factors are missing, the first is that there is no one conclusive study on the recommended angle that people should apply during the brace for impact position, that is why we have calculated the percentiles for three different angles. The second is that there has not been any Saudi anthropometric data collected, which means that the Saudi population is excluded from the world anthropometric data on seat pitches. However, anthropometric databases are only updated when a new survey is conducted and, as this is a major and costly task, it is not done with great regularity. Thus, we recommend that the next time a survey is conducted, they should take into consideration the Saudi population. Finally, they should also take into account secular trends in anthropology since the trend in the increase in people’s sizes is likely to continue and some allowance for this should be included in any new requirements which may have a life of ten years.

Conflicts of Interest: The authors declare no conflicts of interest.

Acknowledgment
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References
3. Chandler R. Brace for impact. Positions, Proceedings of the Fifth Annual International Aircraft Cabin Safety Symposium, Co-sponsored by the University of Southern California, the FAA (Western Pacific Region), and the Southern California Safety Institute, February 1988.

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13. Korte J (2013), South African anthropometric dimensions for the design of an ergonomic office chair. Rhodes University, South Africa
18. Goossens R (1994), Biomechanics of body support: A study of load dis-tribution, shear, decubitus risk and form of the spine. Erasmus Universi-teit Rotterdam, Netherlands
21. Reed M, Schneider L, Ricci L (1994), Survey of auto seat design rec-ommendations for improved comfort. Report of the University of Michigan Transportation Research Institute, USA
22. Japan Standards Association (2002), Ergonomics - Basic human body measurements for technological design